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Thermal analysis of brazing seal and sterilizing technique to break contamination chain for Mars sample return

Xiaoqi Bao[1], Mircea Badescu and Yoseph Bar-Cohen

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

ABSTRACT

The potential to return Martian samples to Earth for extensive analysis is in great interest of the planetary science community. It is important to make sure the mission would securely contain any microbes that may possibly exist on Mars so that they would not be able to cause any adverse effects on Earth's environment. A brazing sealing and sterilizing technique has been proposed to break the Mars-to-Earth contamination chain. Thermal analysis of the brazing process was conducted for several conceptual designs that apply the technique. Control of the increase of the temperature of the Martian samples is a challenge. The temperature profiles of the Martian samples being sealed in the container were predicted by finite element thermal models. The results show that the sealing and sterilization process can be controlled such that the samples' temperature is maintained below the potentially required level, and that the brazing technique is a feasible approach to break the contamination chain.

KEYWORD: seal, sterilizing, Mars sample return, contamination.

1. INTRODUCTION

Future NASA missions are expected to increasingly seek returning samples to Earth for further processing and analysis. These sample return missions may have the objectives of searching for evidence of life in the universe, using the most capable analytical techniques that are available on Earth, as well as possibly preparing for the landing of humans on Mars and beyond. In preparation of such missions, there are considerations to acquire Martian samples, seal them in a container, and store them on Mars for subsequent missions to potentially carry back. Numerous technology developments on sample acquisition, handling and sealing techniques have been published [Younse et al. 2012, 2014, Backes, el al. 2013, Bao et al. 2013]. The issue of planetary protection of Earth is a challenge to potential Mars sample return. Techniques that would reliably seal the "Mars-dirty" container into an "Earth-clean" container, and have assured clean, uncontaminated outer surfaces are critical for "Breaking The Chain" (BTC) of contamination from Mars to Earth. Several methods have been proposed and investigated [Dolgin et al. 2000, Bar-Cohen et al, 2004]. The most critical issue of planetary protection of Earth is living biological contamination. The method of Simultaneous Separation, Seaming and Sealing using Brazing (S^3B) has shown to have the potential

[1] Correspondence: xbao@jpl.nasa.gov

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to assure the containment of the acquired samples in a hermetically sealed container with its exterior free of unsterilized Mars material.

The sterilization method involves need to heat the container to high temperature over 500°C. The temperature of the samples should be controlled to an acceptable level to assure the integrity of the samples. The power required to conduct the brazing process in orbit or on the Mars surface is another concern related to the application of the S3B technique. Modeling work to simulate and analyze the thermal characteristics of the concept designs to apply the S3B method is reported in this paper.

2. FE ANALYSIS FOR APPLYING S3B TO OS IN ORBIT

Finite element approaches were used in the concept development. FE models were constructed to perform numerical analyses and simulations for various concept designs in applications of the BTC technique to the stages of on the ground cache sealing and in-orbit Orbit Sample (OS) container sealing. The models were used to evaluate the characteristics of different initial designs, predict the temperature rise of the samples in the process, perform design parametric study, and optimize the design for better temperature control and low power consumption. Examples of FE model analysis results for preliminarily optimized concept designs for OS sealing are presented in the following sections.

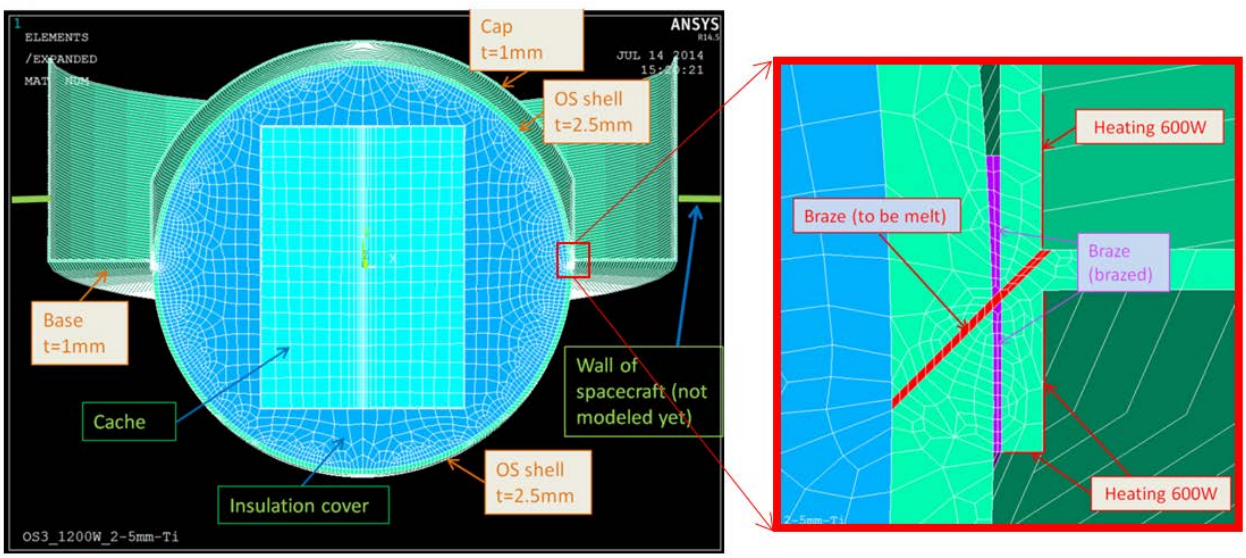

Figure 1: Configuration and FE thermal model showing the OS shell, cap and base made of Ti-6Al-4V or SS316. The insulation cover is assumed to be made of ceramic foam TC1250.

Figure 1 shows a concept design to apply the brazing break-chain technique for OS in orbit. The low half of the OS spherical shell was brazed to the Base structure which is a part of the shell of the Earth Return Vehicle (ERV) in orbit of Mars. The lower space in the figure is inside of the ERV, which is an Earth-clean environment. The Cap and the top half of the OS shell are pre-brazed together. The closed space between the Cap and the top half of the OS shell is also Earth-clean. In this concept, the samples were sealed in a Cache, covered by a spherical thermal Insulation on the surface of Mars and sent to orbit by a Mars Ascent Vehicle (MAV). The Cache is contaminated with Mars dust. The ERV acquires the cache, opens the Cap-OS assembly from the Base-OS, put the

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Cache between them and presses the Cap-OS assembly to the Base-OS. In these operations, the Cache may contaminate the exposed surfaces in the surrounding area. **Figure 1** shows the components are in positions after these operations and ready to perform the S^3B brazing Break-The-Chain procedure.

The zoomed figure on the right of the **Figure 1** shows the details of the area where the brazing of the OS shell and separation of the shell from the Cap and Base would be performed. The two vertical interfaces are brazed joints that are going to be separated. The oblique interfaces are those going to be jointed. When the area is heated to a temperature over the melting point of the braze material a mechanisms (not illustrated in the Figure) would hold the two half OS shells together and move them in to the inside of the ERV while the Cap is continuously being pressed into the Base. After cooling down the two half OS, the shells would be brazed together and seal the cache inside. The outer surfaces of the OS are Earth-clean and the joint interface is sterilized by the high brazing temperature over 500°C. At the same time the Cap would be brazed to the shell of the ERV with high temperature sterilized joint to prevent the contamination from Mars to the Earth-clean environment inside the ERV.

FE thermal analysis was performed to simulate the S^3B procedure for the concept design. The main dimensions are noted in **Figure 1**. The OS shells are made off Ti-6AL-4V or stainless steel. Measured nonlinear thermal properties taken from public literature are used in the simulation. A simplified model is applied to the sample Cache. It is modeled as cylinder with homogenous material having equivalent thermal properties enclosed by a thin wall (0.5 mm) container of Ti-6AL-4V or stainless steel. The equivalent thermal properties are calculated based on a preliminary design of the cache that consists of numerous sample tubes and tube holder. A high temperature insulation material made of ceramic foam (TC1250, Induceramic) is selected for the insulation cover. The melting point of the brazing material is set as 540°C. The thermal resistance, at the contact surface in vacuum before the braze material melted, is expected to be much higher than that after melting. The effect is taken into account by changing the properties of the braze material at the interface sharply around the melting point. The material properties applied to the FE analysis are listed in Table 1. In addition to the heat conduction in solid, the thermal model includes the heat radiation within the enclosure of the Cap-OS and from the outer surfaces to ambient.

Table 1: Thermal properties of materials

Material	Density (kg/m^2)	Thermal conductivity (W/m-C)	Specific heat (J/kg-C)	Emissivity
Ti-6AL-4V	4430	7.04 (0°C)	525 (0°V)	0.2
SS316	7969	12.9 (0°C)	475 (0°C)	0.2
TC1250	380	0.15	740	--
Cache	1737	3.05	620	--
Braze material*	8440	40	343	--

* For the braze material at the interfaces that is going to be jointed the thermal conductivity before melting 0.08 W/m-C to mimic the low conductivity of the contact interface in vacuum which is estimated being 400 W/m^2C.

The assumed ambient temperature and the temperatures of all components at the beginning of the simulation is 0°C. The input power to the two heated areas is indicated in **Figure 1** as 600W for each area. The total heating power is 1.2 kW. The temperatures at six positions in the brazing and

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the separation areas are ploted in **Figure 2**. The results show the required heating time is 167 seconds. At that that time all temperatures in the braze material exceed the fully melting point (540°C). **Figure 3** shows the temperature distribution at 167 seconds. The major heat energy is still limited in the zone surrounding the heating area and very small temperature rise takes place in the cache. The temperatures of the braze material are in the range of from 540 to 556°C and the heating area reaches 586°C at the moment. The total energy consumption is 200 kJ which is an amount the ERV could provide.

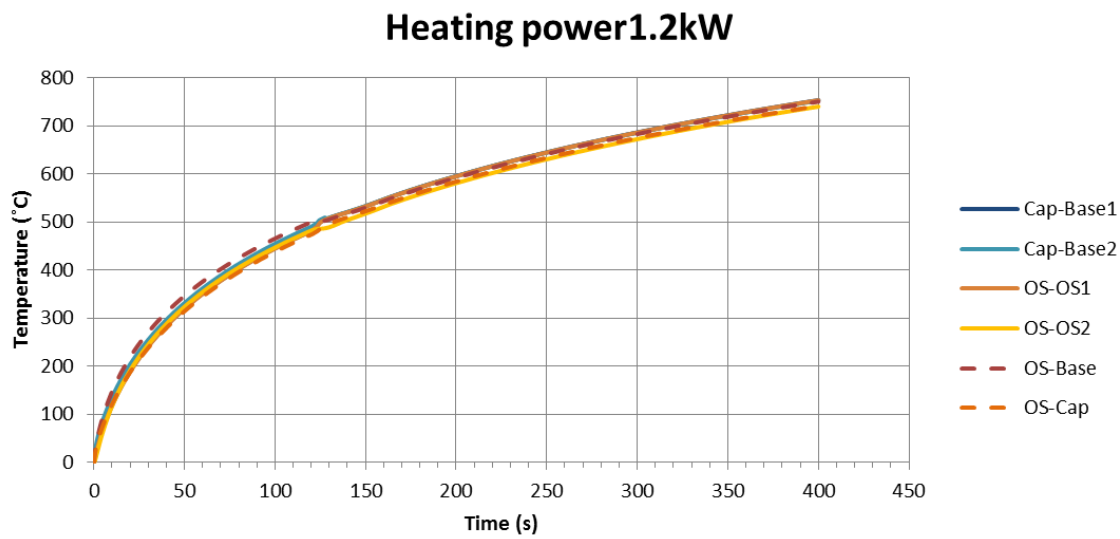

Figure 1 The temperature rise at multiple positions in the brazing area for Ti-6Al-4V OS with 1.2 kW heating power in 0°C ambient. It takes 167 sec and 200 kJ for the temperature to rise over 540°C to melt the braze material.

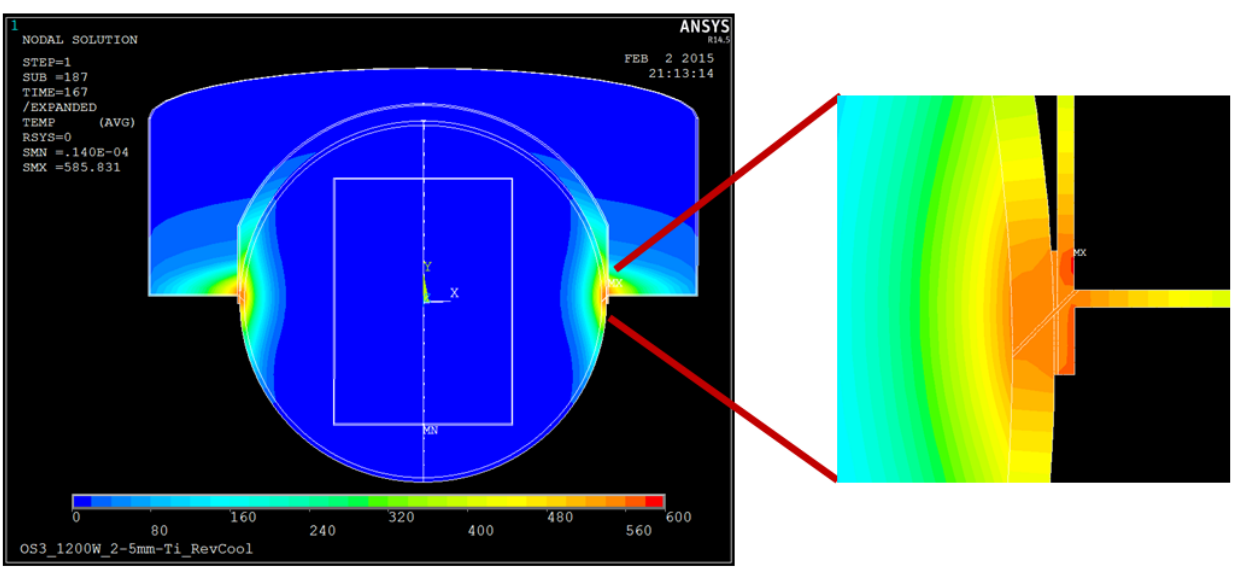

Figure 3: The temperature distribution at 167 seconds for Ti-6Al-4V OS with 1.2 kW heating power in 0°C ambient.

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According to the temperature rise curve, the heating step of the simulated process is set to last for 167 seconds. Then, the OS would be separated from the Cap-base, moved into ERV and cooled down there. Only the radiation loss to the 0°C ambient is taken in account for both the OS and the Cap-base structure. A relatively low emissivity of 0.2 is used. The radiation heat exchange between the OS and the Cap-base is neglected, i.e. the OS is assumed to be moved to a position far away from the Cap-base. The temperatures at the center and the corner of the Cache as well as the temperature at center of the Cap are presented in **Figure 4**. The temperatures at these positions rise first and then fall down after reaching maximums. The maximum temperature in the Cache is 31.7°C, which is an acceptable temperature for sample temperature control.

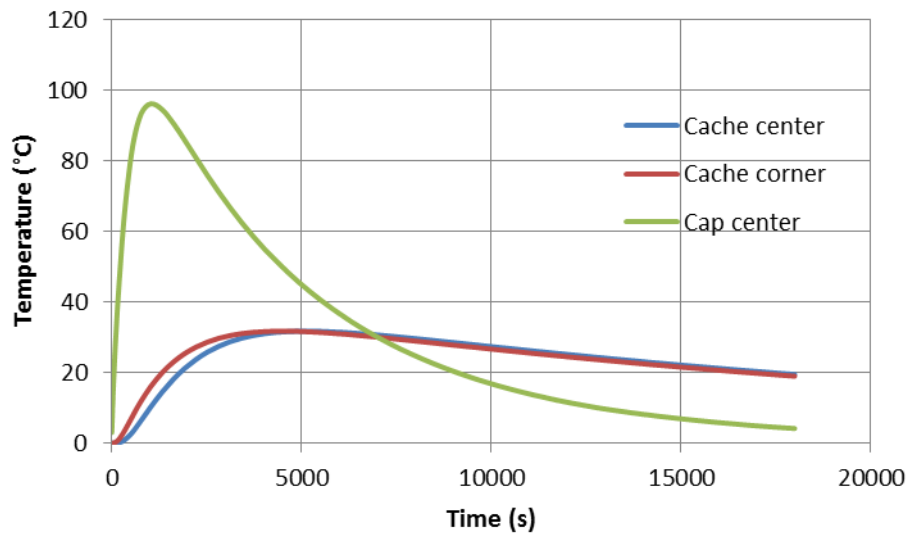

Figure 4: Temperature at cap top and sample cache (center and corner) in 5 hours cooling. The max in sample cache is 31.7 °C at ~80 minutes.

3. SUMMARY

This paper reports development efforts related to the application of the method of Simultaneous Separation, Seaming and Sealing (S^3B) using Brazing technology that is potentially applicable to sample return from Mars or other bodies in the solar system. Finite element models were used to evaluate the thermal behaviors of initial designs, predict the sample temperature rise in the process, perform design parametric study, and optimization of the design for better temperature control and low power consumption. The results of preliminarily optimization of the concept design for OS sealing show that the power, energy consumption and temperature rise of the samples could be controlled to acceptable levels. It is promising to consider applying S^3B technology to future sample return missions to assure planetary protection of Earth.

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